Industrial Waste Management through Material and Energy Recovery: The Case of Hwange Power Station, Zimbabwe

Steven Jerie*, Baldwin Jenya

Department of Geography and Environmental Studies, Midlands State University, Gweru, Zimbabwe

* *Author for Correspondence:* jeries@staff.msu.ac.zw

ABSTRACT
The aim of this study was to examine industrial waste minimisation through material and energy recovery at Hwange Power Station in Zimbabwe. This project is significant in that it envisages the opportunities of boosting power output through the use of industrial waste management at international and national levels. Most industries in Zimbabwe are facing challenges in the sustainable waste disposal and the nation at large is experiencing severe power shortages. A detailed descriptive study was undertaken to analyse the potential of boosting power output whilst sustainably managing industrial waste. The research administered 200 questionnaires which are approximately 30% of the entire population directly involved in the core waste generating activities. Out of the 200 questionnaires that were administered, a total of 182 were completed and returned in time for data compilation giving a response rate of 88.5%. The qualitative and quantitative research designs were used with direct field observations, interviews and questionnaires as primary sources of data. Secondary data was acquired from existing literature to boost and support the research findings. The main findings of the research divulged the types and quantities of waste from power generation activities, the effectiveness of the current methods of waste management and the definitive degree of waste management through material and energy recovery at Hwange Power Station. The study also revealed that energy and material recovery are essential methods of industrial waste management as well as opportunities for boosting power output. It was therefore recommended that Hwange Power Station needs to consider investing in energy recovery to boost power output at the same time sustainably managing waste.
Keywords: Industrial Waste, Minimisation, Material and Energy Recovery, Power Output, Zimbabwe

INTRODUCTION
Globally, many nations are accepting materials and energy recovery technologies due to their ability to produce useful outputs from the waste at the same time effectively and efficiently managing the waste. The benefits of energy recovery are realised through the generation of power, which comes in the form of electricity, gas and oil *inter alia* [1]. On the other hand, materials, recovery is paramount in transforming waste materials as raw materials used to make new items. As contended by [2], it is, however, noted with great concern that the adoption of Waste to Energy technologies is mainly significant in the developed countries due to the huge financial demands associated with them. As stated by [2] Waste to Energy (WTE) does not only produce energy but also saves on space as the cumulative waste produced after energy recovery activities represents approximately 10% of the entire volume of waste produced prior to recovery. An analysis made by the United States Environmental Protection Agency [3], realised that the problems arising from industrial waste might be mitigated using innovative technologies available.

Industrial waste management and energy shortages remain a concern the world over whereas little or no research was done on the possibility of transforming waste into energy as a means of recovering energy. To this end, an analysis of how industrial waste presents an opportunity for energy recovery becomes significant on the international scale. The importance of this study is realized through establishing whether converting industrial waste into energy recovery will be able to assist in the management of industrial waste as well as allow a subsequent increase in energy output. The research outcome of the research anticipates benefiting stakeholders in the power generation industries and related disciplines nationally and internationally since the results can be used to develop global models. The research is significant as it is hoped to benefit the cooperate world in establishing the various opportunities embedded in industrial waste as well as insinuating whether industrial waste can be reduced by means of energy recovery. The study also highlights potential areas of imminent research as it provides a rational elaboration to the basic but more detailed understanding of energy recovery through the use of industrial waste. The product of this research may be used on an advisory basis by the Ministry of Energy and Infrastructural development of Zimbabwe for policy formulation.

The harnessing of energy from waste is currently popular in the conversion of municipal waste into energy. To support this assertion [4] states that WTE plants consumed approximately 1500 million tons of Municipal Solid Waste (MSW) generated in the European Union in the year 2005 alone whereas the fusion of the same technology in handling industrial waste is still minimal. Table 1 represents the breakdown of the total waste conversions in the year 2005.

Table 1: Waste to Energy conversions [4]

Nation	Million metric tonnes to WTE
EU 25	48.8
Japan	40.0
USA	26.3
Taiwan	7.0
Singapore	4.0
China	3.0
Switzerland and Norway	3.8
South Korea	1.0
All Korea	9
Total	143

Deriving from the data presented in Table 1 it is realised that Africa is lagging in terms of commitment towards waste to energy conversions (energy recovery). [5] argue that failure to commit to WTE technology represents a huge loss of revenue, employment opportunities and ultimately energy. The arguments brought forward by [4] demonstrate that Africa is lacking commitment in the adoption of WTE technologies and thus exerts pressure on the natural resources for energy generation and ultimately struggles with waste management.

According to [6], in the United States of America, the amount of hazardous waste generated by manufacturing industries has increased from an estimated 4.5 million tons annually after World War II to some 57 million tons by 1975. By 1990, this total had shot up to approximately 265 million tons. Waste generation is at every stage in the production process, use and disposal of manufactured products [7]. Challenges in waste management manifest in the inability to prioritise the need to have sound and sustainable waste management systems by industries thus missing opportunities for recovering energy. Invariably, economic development is at any given time accompanied by increased consumption of materials and a corresponding increase in the generation of waste. This phenomenon is uniform in both developed and developing nations. As quantified by [4], a survey done in 2004 on waste management in the United States of America (USA) showed an increase in waste generation. An increase of up to 353 from 336 million tonnes between 2002 and 2004 was noted thereby depicting a 2.5% increase rate per year. According to Table 2, most of the waste generated in the USA during the period under review ended up in landfills. In the year 2004 alone, 64.1% of waste was ferried to the landfills and hence showing underutilisation of potential energy embedded in waste.

Table 2: Waste use analysis in the United States of America [4]

	MSW Waste generated	Recycled or composted	Waste To Energy (WTE)	Landfilled
2004 (million tons)	352.6	100.4	26.3	226.0
2004 percent	100%	28.5%	7.4%	64.1%
2002, (million tons)	335.8	89.6	25.8	215.3
2002 percent	100%	26.7%	7.7%	65.6%

[8] postulates that Africa as a whole relies mostly on conventional waste management methods with most of its waste dumped in open space. He further defined conventional waste management as one that focuses largely on waste collection, treatment (composting and incineration) and disposal (landfills). From the assessment made it is thus realised that only partial attempts are underway to adopt integrated waste management practices. Considering all facets of waste generation (industrial and municipal), it is realised that minimal attempts are being realised to embrace energy recovery. Integrated Waste Management covers but, is not limited to waste reduction at the source, resource recovery and recycling. [1] is for the argument that the resource value of waste is realised through separation of waste at source for alternative use and hence energy recovery.

The first step towards prevention and control of pollution of industrial wastes is a full understanding of amounts, types and effects of waste generated. This only becomes operational if there is a commitment to harmonise waste management an aspect that most organizations in Africa lack. Industrial solid waste poses a serious challenge to municipalities and countries, as waste ends up competing with humans for land and financial resources to make it safe [9]. The intrinsic characteristics of industrial waste include occupying land when stockpiling, dumping, disposing or storing, having large categories and quantity thus destroying the astatic value of nature and altering the atmospheric composition. To have sound waste management system industries need to invest and commit to sustainable waste management. African industries are losing a lot of energy embedded in waste due to their failure to embrace WTE technologies.

Inconsistencies in waste management also manifest as a result of ignorance demonstrated by most managers on the need to invest in technologies that will enhance sustainable waste management. A study by [9] on Lake Victoria in East Africa revealed that biological oxygen demand (BOD) load is highest on the Kenyan side of the lake because of the disposal of industrial waste into the lake. From their argument, it is qualified that industrial waste discharged into the water bodies affects BOD. Waste deposited in the lake contains an array of potential energy, which could be harnessed through the adoption of WTE technology at a local scale. The survey realised that BOD loads on the Kenyan side can be reduced by up to 50% through adopting energy recovery technologies.

According to the Environmental Management Agency of Zimbabwe [10], industrial and domestic waste mismanagement presents a topical issue in the country. The failure by industry to invest in WTE technologies has resulted in several environmental problems in and around the country. Investing in sustainable waste management will enhance energy recovery in the various industries, which will also boost energy supply. A survey done by the City of Harare in conjunction with the Environment Management Agency [10] revealed that "as a result of challenges in industrial waste management over 200 companies in Harare's major industrial sites have been found dumping excessive pollutants in rivers that supply the city with water. The magnitude of this problem will be reduced if industries embrace WTE technologies and thus manage waste on point of generation. The bulk of the waste deposited into the natural environment can further be absorbed and used for alternative purposes through embracing WTE technologies. The Zimbabwe Power Company (ZPC) is one of the players in the Zimbabwean industries as well as a contributor to industrial waste generation. The challenges experienced by the company in waste management are somewhat a result of its failure to embrace energy recovery options. Having this background, it is, therefore, the purpose of this research to substantiate how industrial waste presents an opportunity for energy recovery.

A growing population and desired economic recovery in Zimbabwe are resulting in increased energy demand, and a subsequent increase in volumes of waste generated at Hwange Power Station. The vast amounts of waste generated at Hwange Power Station are not being effectively managed and thus resulting in environmental problems such as pollution at various levels. Mismanagement of waste generated is subsequently resulting in the underutilization of the potential energy that is embedded in the waste. The magnitude of the environmental problems is magnified by the absence of recycling infrastructure, which will enable the separation of waste at the source and diversion of waste streams to material recovery. Pressure is being mounted on the natural resources for increased output in terms of the power generated whereas some resources are being thrown away as waste. Waste is generated at various levels can be reintroduced into the energy generation cycle as input in various ways thus energy recovery.

Hwange Power Station is struggling with industrial waste management as most of the waste generated ends up at the open dump (scrape yard) or in the rivers as effluent. This scenario is posing multifaceted adverse impacts on the environment. Current waste management practices at Hwange Power Station accommodate the discharge of effluent in the nearby stream thereby threatening fauna and flora. This predicament is somewhat amplified by the perceived ideology that investing in sustainable waste management is a liability rather than an asset in industrial governance, [10]. The composition of effluent discharged into the streams at Hwange Power Station is composed of all sorts of components, which among them include oils, grease and sewage among others. Effluent discharged in the streams affects water quality and poses a threat to animals. To this end, the problem identified may be eliminated through embracing various technologies, which among them include waste to energy. This paper aims to examine the strategies employed at Hwange Power Station firstly examining related literature and then providing the methodology used in data gathering as well as the results and lastly the conclusion and direction for future research in this area.

MATERIALS AND METHODS

Study area

Hwange Power Station has located in the North-Western part of Zimbabwe approximately 335 Km from the city of Bulawayo, which is the provincial capital for Matabeleland. The power station is situated at approximately 25°45′E to 27°25′E of the Greenwich Meridian (GMT) and 18°53′S to 19°30′S of the equator. Hwange Power Station lies at about 770 meters (2530 feet) above sea level with fine to medium-grained sandy soils, with virtually no clay and silt-sized particles.

Research design

The research adopts a quantitative, cross-sectional design which, as postulated by [11], involves the collection of data on relevant variables. The independent variable, in this case, is the generation of waste while the dependent variable is the opportunity for energy recovery. The energy recovered is largely dependent on the type and amount of waste generated. The quantitative study sought to substantiate industrial waste generation as an opportunity for energy recovery. An analysis by [12], values a quantitative study as an inquiry, founded on testing a principle made up of measurable variables. The variables are analyzed with the use of statistical procedures to determine the authenticity of the predictive simplifications of the theory. This research adopts data triangulation that is a fusion of qualitative and quantitative approaches to describe what exists with respect to variables under study. The research also makes use of a survey method utilizing questionnaires, observation checks lists and interviews to assess the challenges of industries in waste management and how the generated waste can be transformed into energy. A cross-sectional design, which is a fusion of a case study and experimental approach is thus employed. The fusion seeks to satisfy the relationship between power generation activities, waste generation and waste reduction through energy recovery. The thrust behind employing the case study approach is the desire to address the limited time available to address various industries in the country.

Research instruments and data collection methods

The population targeted for this research encompasses all employees, directly and indirectly, involved in power generation. This decision was reached after a consideration that this population is directly involved in the waste generating activities. Furthermore, the identified population is also responsible for carrying out the waste management activities and thus is the source of information pertaining to the efficiency of the current waste management processes. Employees directly involved in power generation under the Operations and Maintenance departments are on the focal point for the questionnaires survey because these departments are the major custodians of waste generation and management. Management representatives such as the Engineering Manager, Section Head Risk and Quality, Chief Risk Officer and Personnel from Environmental Management Agency were also targeted as the key informants for interviews.

As insinuated by [13], the sample size is largely dependent on the margin of error the researcher is willing to accept as well as the entire sample size. The research accepted an error margin of +5% as further amplified by [13].

Calculating the Sample Size.

The research is largely reliant on [14] sample size formula, the formula considers two key functions, namely the confidence level and the level of precision in determination of the sample size. The formula assumes a 95% confidence level and a ±5 percent level of precision, the formula is as follows;

$$n = \frac{N}{1 + N(e)^2}$$

Where: n = sample size

N = Population size

e = Level of precision

The research adopted the non-probability sampling technique embracing purposive sampling with a bid of avoiding selecting responses from the same section. As postulated by [15] non-probability sampling entails a situation where the subjective approach is used and renders the probability of selecting the population element unknown. Non- probability sampling techniques include but are not limited to quota sampling, convenience sampling and purposive sampling. In an endeavor to eliminate repetition and bias in data collection probability sampling was then adopted to sample the individuals for questionnaire distribution. The sampled population is a mirror of the entire phenomenon under study, and thoughtfulness was taken when selecting the population to be sampled to avoid at all cost bias in data collection. Thirty percent of each department was sampled randomly to satisfy a true reflection of the entire population. The selection of 30% of the entire populace was based on [16] argument that any sample 25% and above gives a true reflection of the scenario under study without ambiguity. The research administered 200 questionnaires which are approximately 30% of the entire population directly involved in the core waste generating activities. The 200 questionnaires were distributed to all sections on a 30% basis.

The research simultaneously employed the use of primary and secondary data sources, where primary data was harnessed directly from employees using questionnaires, interviews and direct field observations. Secondary data was gathered from already existing literature from related research and research alike. The thrust of using both primary and secondary data sources is to augment research findings and relate the findings to already existing literature pertaining to the issue under study. Primary data collection tools used for this research were questionnaires, interviews and direct observations. These instruments were used in the collection of data which reflects on the various types and amounts of waste being generated and the efficiency of the current waste management practices.

[17] acclaims that structured observation is a fundamental way of actively finding out about the world around us. For the purpose of this study, observations were carried out to have a glimpse of the existing ways of waste management and the current methods of enhancing energy recovery if any exist. Observations also helped in the identification of the various types of waste being generated at Hwange Power Station. The structured observation checklist was used to guide the researcher as well as record the findings. To augment observations where necessary photographs were captured for the presentation of evidence. For the purpose of this research, the main source for secondary data is literature, information relevant for research alike was gathered from already existing work to augment the research.

Data Analysis

The scope of the research was more of a quantitative nature thus rendering the Statistical Package for Social Sciences (SPSS) the best tool for data analysis. The package is flexible as it enabled the researcher to execute various data analysis procedures. The data analysis activities performed include but were not limited to validity and reliability test, normality test and hypothesis testing.

Research Ethics and Data Credibility

According to [18], ethics in research ensures that no individual is harmed or suffers adverse consequences as a result of any activity during the research. The researchers accepted liability to protect the rights of the respondents by abiding to use and disseminate data collected specifically and meticulously for academic purposes only. The research was carried out in full honesty and total avoidance of deception following the research code of ethics. To satisfy the entirety of the scope and purpose of the research was disclosed to ensure voluntary participation in data collection. Coupled with this, the researcher worked to their best ability to ensure that the research did not cause any harm, embarrassment, stress, discomfort or pain to any of the respondents. Furthermore, the researchers respected the participants' right to refuse to partake at any given stage of the research study. Guided by the research ethics the researchers ensured that all participants at the basis of anonymity and confidentiality were respected.

RESULTS AND DISCUSSION

The process flow of power generation

The various processes involved in the entirety of the power generation of the Power Station are shown in Fig. 1. The essence of having a glimpse of the power generation process is to give an insight into the core business and the major activities responsible for the generation of waste. The entirety of the power generation process as illustrated has several complex and minute inputs which culminate into extensive outputs. The whole process will also result in the generation of various unwanted materials which [6] is defined as industrial waste. As shown in Figure 1 the major input for the boilers is coal and this results in the generation of ash as a byproduct of combustion. A close analysis of the entirety of the power generation process and considering the age of the plant it is also worthwhile mentioning that there is constant maintenance of the plant to ensure continuity and continual improvement. The noted cause results in the generation of high volumes of disused and decommissioned components which can be used for material recovery. The process shown in Fig. 1 is also responsible for the generation of liquid waste (effluent) from the boiler discharge as well as the various operations that use water either for cooling or for cleanup. Regardless of the fact that the power generation process is more of a closed system with minor losses and leakages, there is constantly replacement and lubrication of components which results in the generation of waste at various levels. Apart from the power generation process, there are also activities that support but are not directly involved in the power generation process. Supporting activities such as vehicle maintenance, material fabrication in workshops and the canteen work among others are also involved in the generation of large quantities of waste. The totally of the waste is quantified as industrial waste as it is generated solely as a function of industrial activities.

Types of waste generated

As shown in the process flow chart for the power generation, the major input is the coal used to fire the boilers as well as water used in turning the turbines. The wholeness of the processes involved requires the use of grease and oil for lubrication and thus results in the use of a multiple numbers of lubricants. The processes highlighted in Fig. 1 subsequently result in the generation of waste as classified below.

Effluent

Operations involved in power generation are highly mechanized and use a lot of steam and various lubricants. The unwanted liquid waste from the power generation processes is termed effluent. The effluent at Hwange Power Station is composed of various components including but not limited to boiler effluent from the blowdown activities, grease from surface cleaning and slurry from the various activities. The effluent mainly comes from the following operations:

- Boiler cleaning.
- Boiler blown down.
- Surface water wash.
- General water cleaning of plant and equipment.
- Sewage.

Waste oil

Waste oil is also realised in its bulkiness at Hwange power station and these oils may end up polluting the environment. The bulk of the waste oil at Hwange Power Station comes from the garage since the power station runs a large fleet of vehicles and earth moving equipment. In addition, oils also come from contaminated lubrication oil which would have surpassed its life and lost its viscosity.

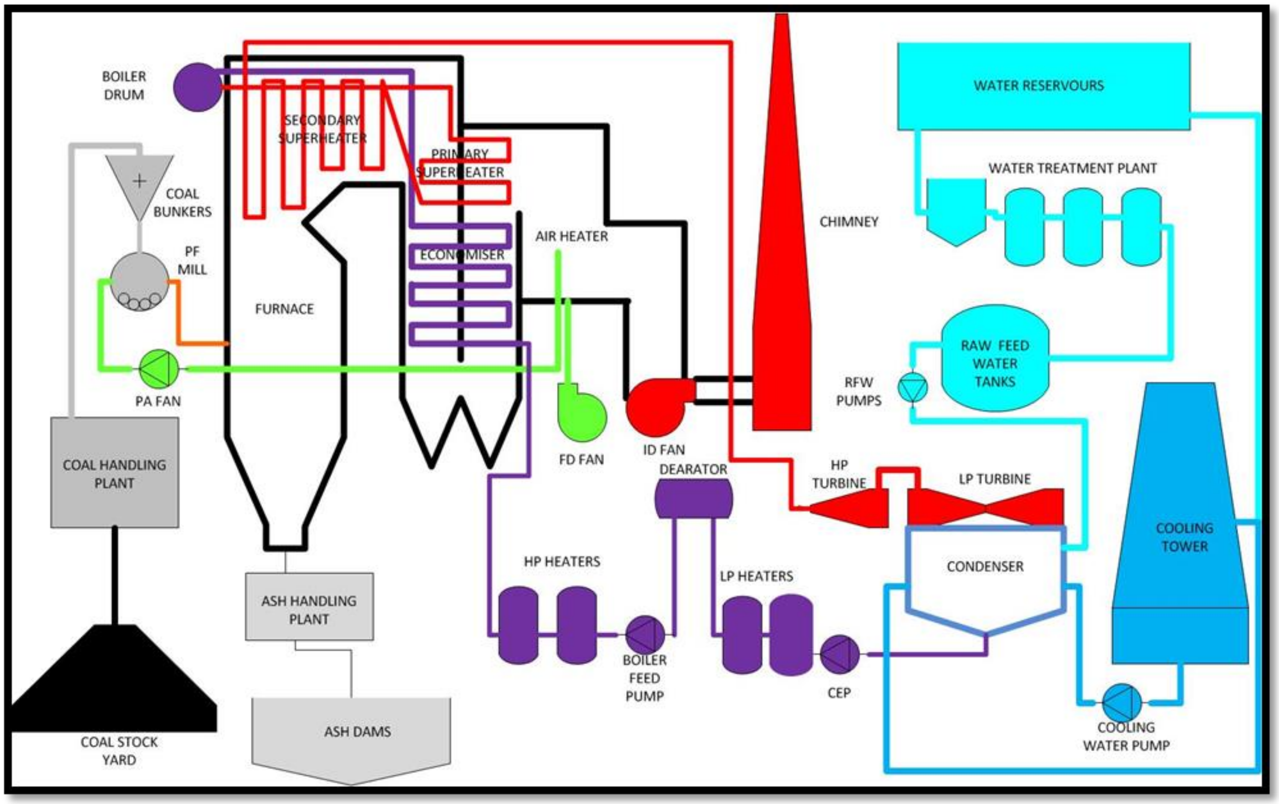

Fig. 1: Process flow chart for Hwange Power Station

Scrape (electrical cables and metal)

As a result of wear and tear and the upgrading of structures to conform to technological upgrades, Hwange Power Station ends up with large volumes of scrape. The composition of scrape is composed of metal aggregates and electrical cables harnessed from rewiring activities. The bulk of the scrape is dumped at the scrape yard (open dump)

Solid waste-paper, electronic waste and plastic

For the purpose of this research minute aggregates of waste were grouped under the name of solid waste. The solid waste is composed of paper, pet bottles, plastic, polythene and kitchen waste from the canteens. All solid waste generated in the Power Station is dumped at the Hwange Collier Company dumpsite.

Wood aggregates and construction rubble

The bulk of the wood aggregates comes from crating and pallets used in the packaging of spares and other substances procured within the Power Station. The disposal method for these wood aggregates is mainly deposition at the local scrap yard where the wood will be exposed to all weather conditions. Little or no energy is being recovered from the wood aggregates found within the Power Station.

Ash

The largest amount of waste generated is found in the form of ash amassed from combustion in the boilers. The ash is dumped at the Ash dams without any alternative uses. Both bottom and fly ash is mixed and transported by water to the Ash Dams (open dumping).

The average quantity of monthly waste generated

Table 3 shows the average waste generated in a period of a month within Hwange Power Station. Variations may exist depending on the activities underway, for instance during a unit outage the amount of average waste is bound to be on a high owing to an increase in the replacement of worn-out material such as scrap metal. The information in Table 3 is an approximate generalized average volume of the monthly total volume of waste generated as due to the nature of the operation it is difficult to have precise volumes of total waste generated. The power generation activities and the maintenance of plant and equipment adopt skewed and rather undefined paths and the activities are not routine. Furthermore, some activities do not have a defined time frame and thus quantifying the waste generated to a particular month becomes difficult. Maintenance jobs can overlap thus making it rather difficult to account for the monthly waste generated.

A Chi-square test was computed to query the hypothesis to determine the association between types of waste and energy and or material recovery from industrial waste. The test result showed that $P<0.05$ and hence there was a strong association between energy recovery and waste generation.

Table 3: Monthly waste generation

Type of waste	Quantity
Sewage.	996 000 liters
Effluent.	891 000 liters
Waste oil.	2 000 litres
Solid waste.	24 tones.
Scrape.	18 355 kilograms
Wood aggregates.	7 tones.
Construction rubble.	10 Tones.

The efficiency of the current waste management strategies

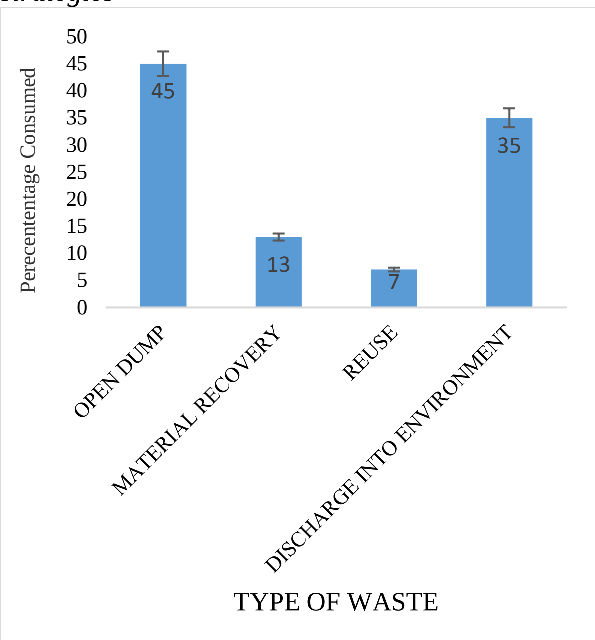

Fig. 2: Efficiency of current waste management strategies

As highlighted in Fig. 2, 45% of the total waste generated at Hwange Power Station is being ferried to the open dump where no energy is recovered. Material recovery constitutes approximately 13% and this is realised from scavenging of components from the waste dump. Of the total waste generated a subsequent 35% is dumped into the natural environment either as effluent or in its solid-state. The amount being reused only accounts for 7% of the totality.

As In Fig. 2, the totality of the waste being ferried to the open dump demonstrates a gap in energy loss. From their argument, natural gas accounts for approximately a GCV of 42.0MJ/m^3. The methods being employed at the Hwange Power Station does not harness any energy from the waste and only 13% is being account for as material recovery. Cumulatively of the average total waste generated at the Power Station, only 13% is being put to good use through energy recovery with the remaining 87% going unaccounted for. This thus demonstrates that the methods at Hwange Power Station are ineffective in dealing with the waste generated.

According to Fig. 3, the combustion of waste converts chemical energy Lower Heat Value (LHV) into thermal energy of combustion gas at high efficiencies. The current practice at Hwange Power Station results in the emission of CH_4 from landfills (dumpsite and scrape yard), spontaneous combustion at the dumpsite releases the fossil carbon in the fuel into CO_2 and biogenic carbon. The release of these gases has the potential of causing global warming through the release of greenhouse gases into the atmosphere. In Fig. 3 the least efficient value that can be attained from the waste conversions is approximately 60% that is harnessed from 13 MJ/Kg of LHV. The variations can be subjected to moisture contained in the waste which thus compromises the ability to harness a higher note in thermal efficiency. The practice at Hwange Power Station does not cultivate by any means energy embedded in the waste and thus attains zero thermal efficiencies. On average, thermal efficiency ranges between 80 and 120 % and thus harnessing the potential energy from the waste. With the current waste management practices at Hwange Power Station, the company is missing out on potential energy buried in waste.

The efficiency of current waste management strategies and the definitive degree of energy recovery

Hypothesis testing was performed to determine the applicability and authenticity of the obtained results through querying the relationship between the variables under study. Broadly hypothesis testing was done to assess the efficiency of current waste management strategies at Hwange Power Station. In addition, hypothesis testing was also undertaken to explore the definitive degree of waste management through material and energy recovery at Hwange Power Station.

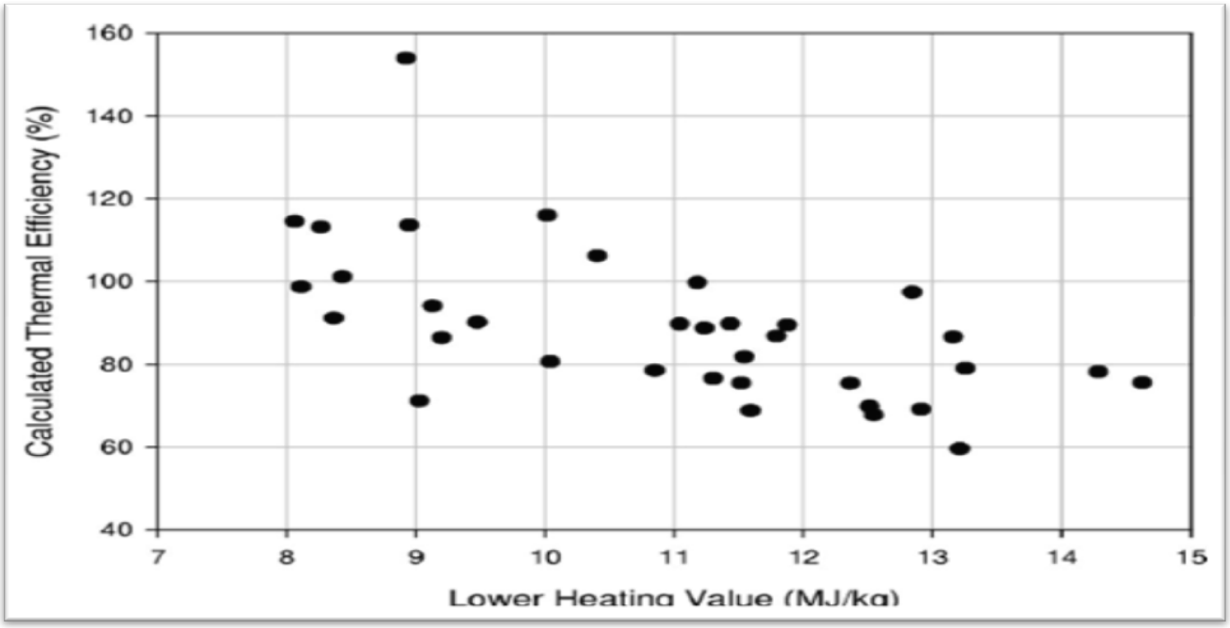

Fig. 3: Fuel efficiencies for steam production versus Lower Heat Value in incineration

Correlations

The study employed Pearson`s product-moment correlation in SPSS to ascertain the strength of the relationship between the variables under study. Establishing the strength of the relationship between the variables is paramount in assessing the efficiency of current waste management strategies as well as exploring the definitive degree of waste management through material and energy recovery at Hwange Power Station. The test result showed that there was a strong relationship between total waste generated and material and energy recovery with a correlation coefficient of +0.954 significant at 0.01 level. There is a strong positive correlation between the waste generated and the potential energy and material that can be recovered. Deriving from the analysis energy and material recovery is suffering as no attempts are being made to harness energy from the waste available. According to interviews with the key informants, Hwange Power Station is not in any way harvesting energy embedded in waste. It was also highlighted that a lot of revenue is being lost through the inability to recover materials as the process of procuring waste goes through a cumbersome process which in turn affects the potential for material recovery.

Regression Analysis

The analysis of the relationship between energy recovery and waste generation realized a correlation coefficient of 0.566, the correlation depicted was significant at the 0.000 level. According to [12], correlation coefficients beyond 0.5 implies a high positive correlation and thus there is a strong positive correlation between energy recovery and waste generation. Therefore, it follows that there was a high correlation coefficient that was established to exist between energy recovery and waste generation.

Having established the existence of a significant correlation between waste generation and energy recovery (the dependent and independent variable), simple regression was computed to determine the outcome of the potential embracing of the energy recovery technology. The regression coefficient for the relationship between waste generation and energy/material recovery stood at 0.566, and the corresponding r-square statistic was 0.18. The derived 18% is a result of the material recovery being practiced at the Power Station and thus satisfy the essence of material recovery. The high residual of 87% is attributed to the failure to attain both material and energy recovery which has subsequently resulted in missing out in terms of power generation. The analysis done thus demonstrates that the company is losing a subsequent volume of potential energy as a result of failing to invest in energy and material recovery.

CONCLUSION

Hwange Power Station is missing out in terms of energy opportunities due to the failure to embrace material and energy recovery options. Regardless of the fact that the energy and material recovery options are not at the apex of the waste control hierarchy, these options remain vital in reducing waste as well as boosting output. More so the current practice of waste management being employed at Hwange Power Station is detrimental to the natural environment as they have the potential to cause environmental pollution. Environmental pollution is being realized from the direct disposal of effluent into the Deka River. Environmental pollution is also being realized as a result of the open dumping of industrial waste. Open dumping of waste at the scrape yard as well as the open dumpsite results in the release of greenhouse gases released during decomposition.

Failure to invest in material and energy recovery by the Zimbabwe Power Company has resulted in the loss of revenue by the Company. Subsequent amounts of cash are being remitted to the Environmental Management Agency (EMA) in the payment of fines for environmental pollution. The paying of vast amounts of fines for polluting the environment could be circumvented through the recovery of all the waste generated through various processes. The bulk of the fines being paid to the Environmental Management Agency is as a result of the direct discharge of waste (effluent) into the natural streams and the improper handling of waste being practiced under the current waste management methods.

The study revealed that energy and material recovery are paramount methods of dealing with industrial waste. The aforementioned methods are capable of reducing waste as well as edifying the total output in terms of power. Energy/ material recovery is also capable of reducing the total costs incurred by the organization through the payment of pollution fines. The management at Zimbabwe Power Company should consider investing in sustainable waste management through embracing energy and material recovery to circumvent costs associated with poor waste management. Further studies should focus on how to advise Hwange Power Station authorities to consider adopting environmental management systems such as ISO 14001. This will go a mile in disseminating information pertaining to the effects of industrial waste at a broader scope. Environmental management systems will also help transform employee attitudes towards environmental management. This also includes how Zimbabwe Power Company could consider investing in energy recovery technology to boost power output from the power stations. Technologies such as the biogas power plants could be adopted to utilize waste from sewage and effluent.

ETHICAL ISSUES

Ethical issues have been observed by the authors.

CONFLICT OF INTERESTS

None to be declared

AUTHORS' CONTRIBUTIONS

All authors equally helped to write this manuscript.

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